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FLIGHT EXPERIMENTS AND EVOLUTIONARY DEVELOPMENT OF A LASER PROPELLED, TRANS-ATMOSPHERIC VEHICLE

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ABSTRACT

In a series of spectacular experiments conducted at the High Energy Laser Systems Test Facility (HELSTF), White Sands Missile Range (WSMR), NM, using 13- to 15-cm diameter, 40- to 60-g vehicles designed to fly on the 10 kW PLVTS pulsed carbon dioxide laser (1kJ pulses for 30 us duration at 10 Hz), Prof. Leik Myrabo of Rensselaer Polytechnic Institute (RPI) and Dr. Franklin Mead of the Air Force Research Laboratory's (AFRL) Propulsion Directorate, have been successfully flying laser propelled Lightcraft under a joint Air Force/NASA flight demonstration program. The axisymmetric Lightcraft vehicles are propelled by airbreathing, pulsed-detonation engines with an infinite fuel specific impulse. Impulse coupling coefficients have been measured with ballistic pendulums as well as a piezoelectric load cell and fall in the range of 100 to 200 N/MW. Horizontal wire-guided flights up to 400 ft, using a unique laser beam pointing and tracking guidance system, have demonstrated up to 2.0 G's acceleration measured by a photo-optic array. Spin-stabilized free-flights with active tracking/beam control have been accomplished to altitudes of 15.25 meters. This paper will summarize the progress made to date on the Lightcraft Technology Demonstration flight test program, since the first 12-14 July 1996, experiments at HELSTF.

BACKGROUND

The "Lightcraft Technology Demonstrator (LTD)", is a laser propelled, trans-atmospheric vehicle (TAV) concept developed by Prof. Leik Myrabo at Rensselaer Polytechnic Institute (RPI) for Lawrence Livermore National Laboratory and the SDIO Laser Propulsion Program in the late 1980's.(1) This novel launch system (See Fig. 1) was envisioned to employ a 100 MW-class ground-based laser to transmit power directly to an advanced combined-cycle engine that would propel a 120 kg (dry mass), 1.4 m diameter LTD, with a mass fraction of 0.5, to orbit. Once in orbit, the single-stage-to-orbit (SSTO) LTD vehicle would then become an autonomous sensor satellite capable of delivering precise, high quality information typical of today's large orbital platforms. The dominant motivation behind this study was to provide an example of how laser propulsion could reduce, by an order-of-magnitude or more, the production and launch costs of sensor satellites. The study concluded that a vehicle production cost of $1,000/kg was realizable, and that launch costs must be limited to less than $100/kg for laser propulsion to play a significant role in the future of space transportation. Today our expectations for the use of laser propulsion technology are slightly less ambitious. We envision the launching of 30 to 50 kg Lightcraft vehicles at $1,000/kg using existing high power lasers, and $100/kg as a realizable goal within the foreseeable future.

Figure 1. Lightcraft Launch

Launch of an ultralight Lightcraft involves several steps. First, the Lightcraft is engaged by the laser and lifted off the launch stand. It then accelerates at a fixed angle toward Mach 5. With higher speeds and lower air pressure (due to increased altitude), the amount of thrust will decline. At 30 km altitude, the airbreathing pulsejet engine is shut off. The vehicle continues to coast upward along a ballistic trajectory through the region of the Paschen minimum pressure. At the desired altitude, the craft pitches over into its final horizontal position and begins to receive laser power from a low-altitude relay satellite. The Lightcraft, now in rocket mode, begins again to increase speed to that needed for a circular orbit.

DISCUSSION

The LTD concept that is being flown today, illustrated in Figure 2 as a cutaway model, was, and is today, a microsatellite in which the laser propulsion engine and satellite hardware are intimately shared. Although not shown in this figure, the electronics and payload would be packaged in the forebody section. Tankage for a working fluid, such as liquid nitrogen or hydrogen, would be packaged into the center and aft portions of the Lightcraft. The forebody aeroshell acts as an external compression surface (i.e. the airbreathing engine inlet). The afterbody has a dual function as a primary receptive optic (parabolic mirror) for the laser beam and as an external expansion surface (plug nozzle) during the rocket mode. The primary thrust structure is the annular shroud. The shroud serves as both inlet and impulsive thrust surface during the airbreathing mode. In the rocket mode, the annular inlet is closed, and the afterbody and shroud combine to form the rocket thrust chamber. The three primary structures (forebody, shroud, and afterbody) are interconnected by a perimeter support frame to which all internal subsystems are attached. Superconducting magnets that act as a magnetic nozzle for the laser plasma are not shown but are a possible future development option because it has been shown in past experiments that the thrust can be doubled by their application.(2)

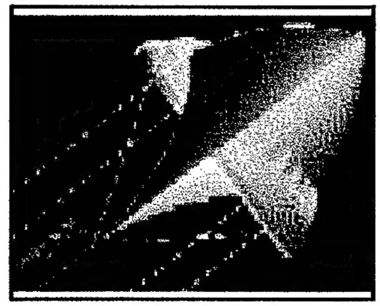

Figure 2. Lightcraft Cutaway

All testing of Lightcraft has taken place at HELSTF with the Pulsed Laser Vulnerability Test System (PLVTS). The PLVTS(3) is a CO_2 electric discharge laser of moderate to high energy per pulse. It consists of several subsystems mounted in portable vans/trailers. This high energy CO_2 pulsed laser device is an AVCO-built HPPL-300 laser. The device uses an electron beam to excite the CO_2 gas and create the lasing action. It is a pulsed wave, closed cycle CO_2 laser with a pulse repetition rate of 1 to 10 pps (selectable), and a pulse width of 30 μs. The PLVTS beam can be extracted from the system by one of two methods. The primary method is through a static Beam Pointing Telescope (BPT). The BPT is a 50-cm cassegrainian telescope which allows manual pointing and focusing of the HEL beam to downrange targets. The second method is through simple turning flats which redirect the 10-cm beam to an external facility for effects testing. Although designed to operate as a stand-alone system, the PLVTS is homesteaded at Test Cell 3 at HELSTF. When operated at HELSTF, the PLVTS can be integrated with the existing HELSTF control, diagnostics, and data acquisition systems. In the stand-alone mode, the PLVTS uses integral control and data acquisition systems based on internal computers. Modifications to this facility are currently underway in order to operate up to 30 pps with pulse widths of 10 μs. The maximum power available will still be 10 kW.

The objective of the "Lightcraft Technology Demonstration" program is to conduct, before the end of calendar year 1998, an flight demonstration to a significant altitude. This will be accomplished by launching a specially designed, ultralight Lightcraft to an altitude of between 0.6 and 10 km using an existing laser at the HELSTF. This launch will demonstrate the viability of laser propulsion for eventual low cost access to space.

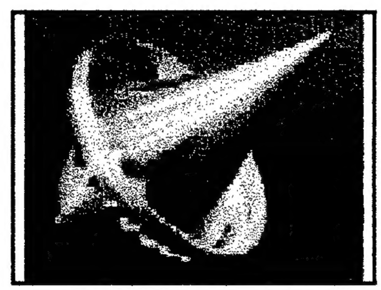

Figure 3. 8-inch Lightcraft

RESULTS

Testing of Lightcraft vehicles began at PLVTS in July 1996, using a 2 kg, all aluminum, 8-inch-focal-diameter Lightcraft (See Figs. 3 & 4). This subscale model was very similar in many details to the Lightcraft envisioned during the SDIO study discussed above. These early tests primarily focused on performance. Tests on a pendulum demonstrated impulse coupling coefficients in the range of 100 to 200 N/MW. The upper value of the coupling coefficient is very close to the value of the German WWII V-1 "Buzz Bomb". The wide variation in coupling coefficient performance was accomplished by placing a thin plexiglas cylindrical extension on the rear of the model to direct the plasma flow in a more collimated reward direction. The results, measured at lengths of L/D, produced a smooth curve that appeared by extrapolation to approach a

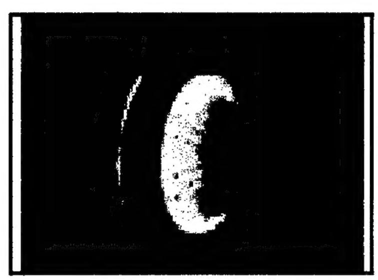

Figure 4. Horizontal Wire-Guided Plasma Pulse in 8-inch Lightcraft

coupling coefficient of 500 N/MW at an L/D=6. This was never experimentally verified. Horizontal wire-guided tests were also conducted in an attempt to accelerate the Lightcraft (See Fig. 4 which show a picture of the plasma produced during a single pulse of the laser). However, the model was just too heavy and there was too much friction in the bearing surfaces. Even attempts to initiate movement by pulling with a chord and letting the laser continue the thrusting did not produce any measurable results.

It was not until the end of the summer of 1997, that significantly long horizontal wire-guided flights and high vertical free flights were accomplished. The first really successful vertical free flight tests occurred in August 1997, with a number of 14- to 15-cm diameter focal length model variations weighing between 50 and 60 g. These flights produced exciting results as a number of flights soared to heights estimated to be between 2 to 3 m. For these flights, the models were spin stabilized and used an active laser pointing and tracking system. Spin-up was accomplished before launch by the use of compressed nitrogen connected by a long hose to a gas jet nozzle which was used to blow on the periphery of the Lightcraft. This approach produced rotational speeds of between 3,000 and 6,000 rpm measured with a strobe light. The launch stand consisted of a vertical wire with an adjustable stop that was positioned to allow not more than ½ inch of wire to protrude from the forebody. Thus, the first laser pulse typically launched the Lightcraft into the air and free flight. This type of flight can be seen in Figure 5. Here, a multi-exposure picture is shown of a typical indoor flight during the August test series. The vehicle is seen to be clear of the launch stand by the time the second pulse occurs. The laser continues to provide power to the vehicle until it moves to such an extreme distance horizontally that the laser tracking system limits are exceeded. This figure shows that there were about 12 pulses on target for this flight. Thus the vehicle flew under power for about 1.2 seconds.

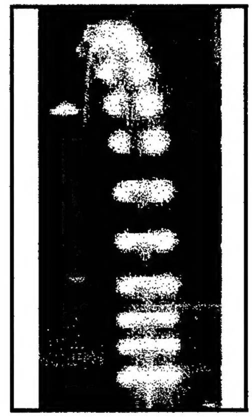

Figure 5. Lightcraft Flight

Also during the August test series horizontal wire-guided tests were conducted outside the laboratory in order to evaluate the new laser beam pointing and tracking guidance system over greater distances. To accomplish this, a wire was strung from inside the laboratory, through an open window, and fastened to a scaffolding framework at a fixed distance. A horizontal wire was chosen not only because it sags, but also because it vibrates as the Lightcraft moves down the length. This then, was considered a good test of the system's ability to keep the laser beam on the target. The horizontal wire-guided flights were conducted up to 130 ft, using the unique laser beam pointing and tracking guidance system, and demonstrated up to 2.0 G's acceleration measured by a photo-optic array. These tests were conducted both during the daylight hours and in complete darkness. For the night flights, very strong spot lights had to be used to illuminate the target, but during daylight hours sunlight was sufficient. In essence, these tests demonstrated that the laser beam pointing and tracking system was adequate up to the maximum distance of 130 ft.

Tests conducted during the last week in September and into October 1997, included additional vertical free flight tests with 14- to 15-cm models weighing less than 50 g. These models were chemically milled to considerably reduce their weight. They were able to reach the maximum available altitudes inside the laboratory which was about 5 m . These flights (see Fig. 6) were very spectacular. Again, the models were spin stabilized, but the laser beam was fixed for these flights (i.e. there was no active tracking). In a typical flight, the Lightcraft accelerated quickly to an altitude where it seemed to move slightly out of the beam. Sometimes, it re-centered itself, but most of the time it drifted out of the beam and fell back down where it was captured in along handled fishing net. By catching the Lightcraft, damage was avoided to the model, which would occur if it hit the cement floor, or to the all important beam turning mirror located beneath the launch stand.

Figure 6. 5 m Vertical Free Flight

Horizontal guided-wire tests outside over a length of 400 ft were again used to demonstrate the laser pointing and tracking system to even greater distances. Both night and day flights along the wire showed that the tracking system would follow the Lightcraft to this ultimate distance

successfully.

During the first week of November 1997, the first ever laser propelled launch tests outside were conducted. The tests utilized a manlifter vehicle to hold a beam dump (4 ft x 8 ft piece of plywood painted black) at varying heights and a 55 ft canvas contoured to a u-shape. The beam dump was required to avoid hitting aircraft or satellites that might inadvertently pass over the test facility. The u-shaped canvas was used to protect personnel working in proximity of the test site from possible glints off the flying vehicle. Test flights were positioned so that they flew within the u-shaped canvas structure. The remaining open side of the canvas structure allowed access to the launch pad and photographic coverage of the flight action. For the first time, in a series of spectacular outdoor laser propulsion experiments using 15-cm diameter, 47- to 54-g vehicles, Lightcraft models were successfully launched to an altitude greater than 50 feet in 5.5 seconds. The tests, conducted from 3 to 5 November 1997, using two different model geometries, achieved four 36-foot flights, one 40-foot flight, and one flight just over 50 feet. As an interesting comparison, Dr. Robert Goddard's first flight of a liquid-fueled chemical rocket occurred on 16 March 1926, and rose to a height of 41 feet. Thus, the best of the first outdoor flights of the axisymmetric, airbreathing, pulsed-detonation Lightcraft vehicles, requiring no onboard propellant for flights within the atmosphere, was higher by 9 feet than Dr. Goddard's historical flight. Additional outside tests to even higher altitudes are scheduled for December. The results of the flights will be discussed during the STAIF-98 presentation in January.

Acknowledgments

1. Members of the PLVTS scientific team included Dr. Stephen Squires, Dr. Chris Beairsto, and Mr. Mike Thurston.

2. Pictures in Figures 3,4,5, and 6 were taken by Mr. James Shryne of W.P. Photographic Services.

3. Funding from NASA was provided through Mr. John Cole and Dr. Jonathan Campbel of Marshall Space Flight Center.

References

1. Myrabo, Leik N. et al., "Transatmospheric Laser Propulsion", Final Technical Report, June 1989.

2. Lyons, P.W. et al., "Experimental Investigation of a Unique Airbreathing Pulsed Laser Propulsion Concept", AIAA 91-1922, AIAA/SAE/ASME 27th Joint Propulsion Conference, 24-26 June 1991.

3. See "Pulsed Laser Vulnerability Test System" at: http://wsmr-helstf-www.army.mil/plvts.html.